

ADVANCED EVA SYSTEM DESIGN REQUIREMENTS STUDY

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PREFACE

The Advanced EVA System Design Requirements study was a twelve month effort to identify specific criteria regarding Space Station EVA hardware requirements by analyses of EVA missions, environments, operations, procedures, and Space Station and STS interfaces. The study began in January of 1985 and was completed in January, 1986.

This executive summary report has been prepared in accordance with the Statement of Work for the subject study, contract NAS9-17299, and summarizes the data and analyses from which all the study results were derived. A detailed report has also been prepared for distribution as determined by the contract monitors.

The study results are intended to provide information and guidelines in a form that will assist NASA program managers in evaluating and substantiating EVA system requirements to support a productive EVA capability for the Space Station Program.

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SECTION 1

Introduction and Study Overview

Introduction

The purpose of this document is to report on the technical work accomplished on the Advanced Extravehicular Activity System Study, Contract NAS-9-17299. The study was performed to define and establish design requirements and criteria for the Space Station Advanced Extravehicular Activity System (EVAS) including crew enclosures, portable life support systems, maneuvering propulsion systems, and related EVA support equipment. The study considered EVA mission requirements, environments, and medical and physiological requirements, as well as operational, procedures and training issues.

1.1 Team Organization

The MDC EVAS Study Team was organized to take advantage of a unique mix of experience and expertise in defining and developing EVA systems, as well as in planning and conducting successful EVA operations. (Figure 1-1). The Houston Division of the McDonnell Douglas Astronautics Company provided overall study management and expert task leadership dedicated to incorporating in this study all the relevant lessons learned while helping NASA develop and exercise the NSTS EVA capability which has been so spectacularly demonstrated in recent years. To this invaluable understanding of EVA operations were added the skills and experience of the Huntington Beach division of MDAC (for physiology, productivity, system integration and compatibility with Space Station architecture); the Hamilton Standard Division of United Technologies (for life support system technologies); ILC-Dover (for crew enclosure, materials and ancillary equipment); and Martin Marietta (for maneuvering propulsion technologies). Corporate EVA experience bases dating back to Gemini IV were thus applied to the purpose of defining EVA system requirements for the Space Station.

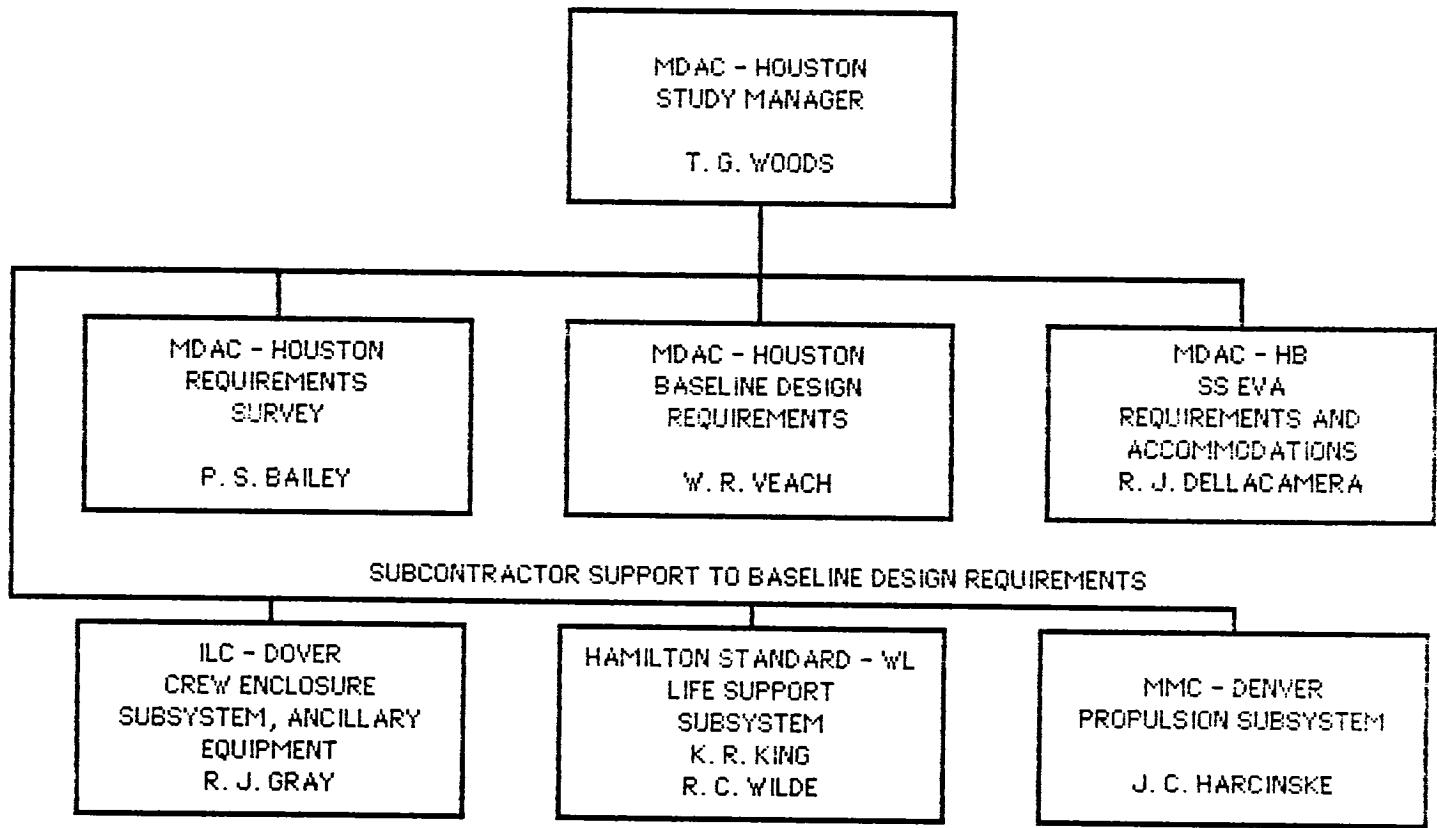
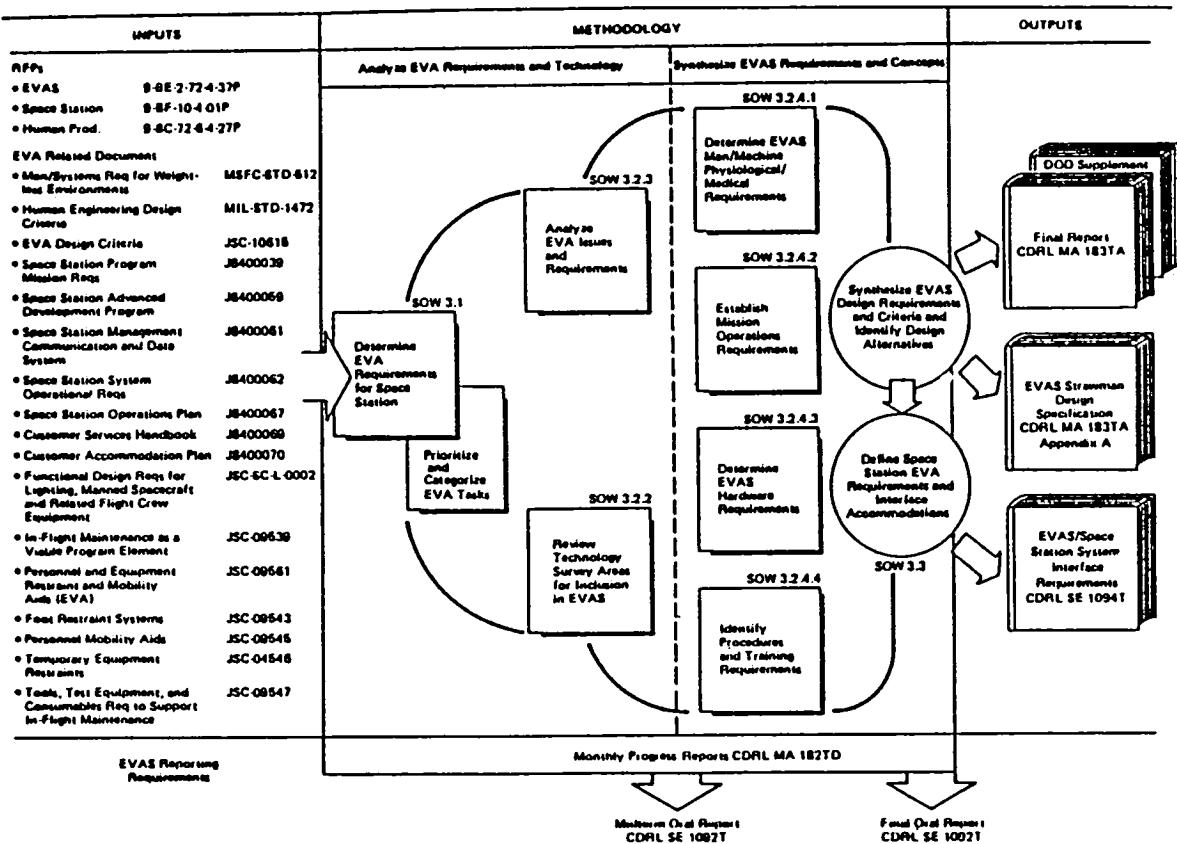


FIGURE 1-1
TEAM ORGANIZATION

1.2 Study Organization

The methodology chosen for this study was a classic Phase A approach of survey, analysis, synthesis and definition as shown in Figure 1-2.



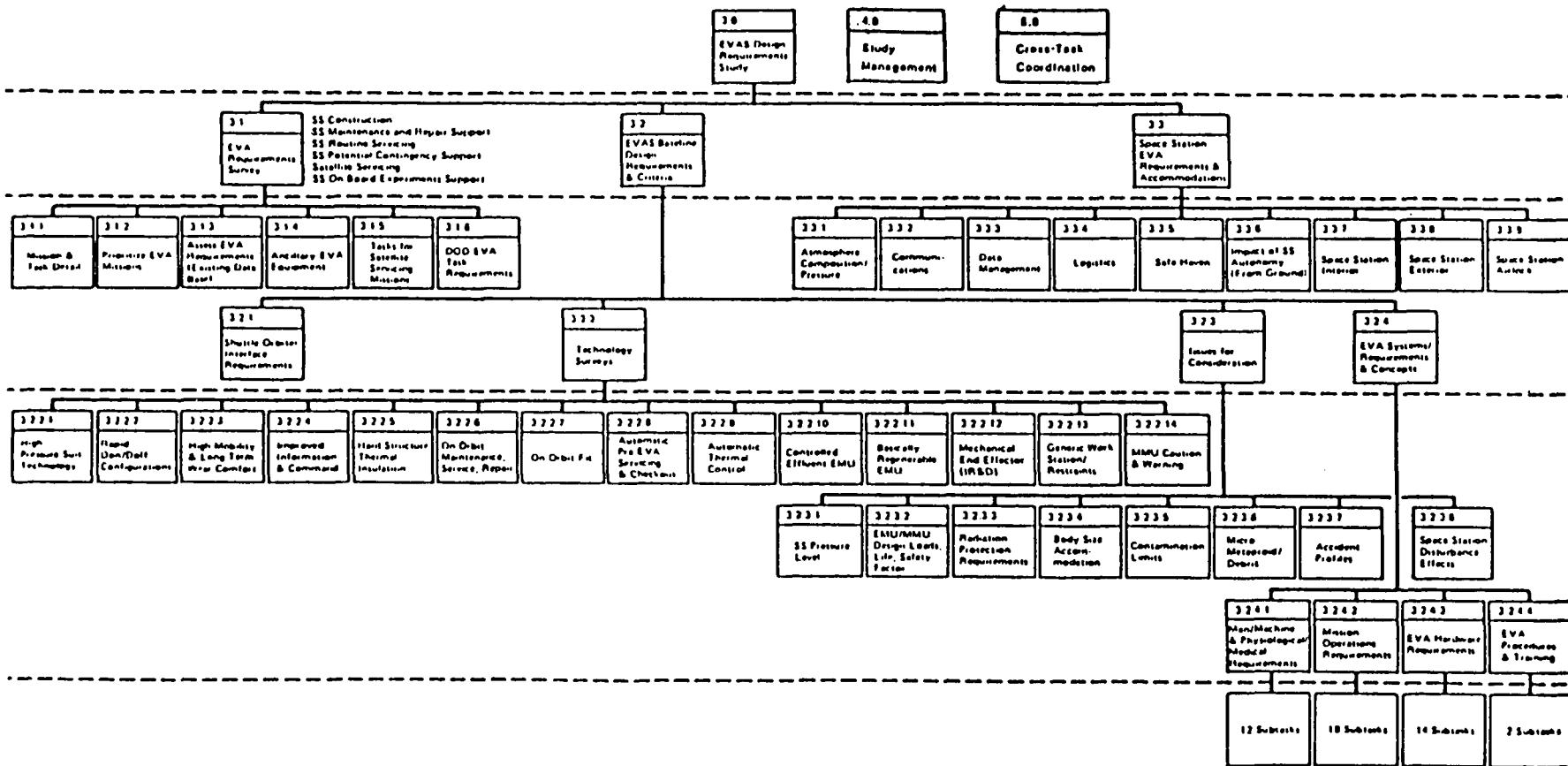


FIGURE 1-3
WORK BREAKDOWN STRUCTURE

1.3 Key Issues and Drivers

Specific EVA system requirements and their rationale are summarized in the ensuing sections of this report. There were several issues and driving considerations developed in the course of the study that affected more than one system and which combined with some unique characteristics of the Space Station to effect many of the EVA design considerations.

1.3.1 Unique Space Station Characteristics

When compared to previous programs, the Space Station crews will be routinely on-orbit for far longer periods, and the vehicle itself and many of its systems will be there virtually indefinitely. From this factor alone were derived several other key characteristics of the Space Station.

- 0 ORBIT STAY TIME GREATLY INCREASED OVER PREVIOUS PROGRAMS
- 0 OPERATIONAL TEMPO RELATIVELY BENIGN
- 0 MISSION PLANNING MORE LONG TERM, LESS PRE-MISSION DETAIL
- 0 TRAINING MORE GENERIC, MORE TASK-ORIENTED, LESS MISSION SPECIFIC
- 0 ON-ORBIT TRAINING REQUIRED FOR PROFICIENCY IN CONTINGENCY/EMERGENCY SITUATIONS
- 0 LONG VS SHORT TERM PHYSIOLOGICAL FACTORS AND ENVIRONMENTAL PROTECTION REQUIREMENTS

FIGURE 1-4
UNIQUE SPACE STATION CHARACTERISTICS AFFECTING EVA

The tempo of operations will be relatively benign with regard to meeting most mission objectives in critical time periods. For instance, an EVA task that takes longer than anticipated can be rescheduled for completion in the next planned EVA event. This takes advantage of the more permanent nature of the manned presence than that afforded by the STS and also alleviates the potentially deleterious effect of less mission specific training available to SS crews. Mission planning itself will be more of a long-term nature on the ground with much less pre-mission daily detail than is required for Shuttle. For the same reasons, and due to the wide variety of EVA mission requirements, pre-mission training will emphasize development of the generic EVA skills that will be required to accomplish them. On-orbit EVA training opportunities will also be utilized to compliment limited ground simulations with an abundance of on the job training to achieve true profi-

ciency. Additional on-orbit training requirements in emergency procedures and off-nominal EVA systems operations are required by the length of crew cycles and by the need to maintain proficiency in safety critical areas.

While much has been learned about adapting man to the orbital environment, there are new, different, and perhaps unknown risks associated with long term exposures. The statistical probability, however small, of a hazardous event or exposure occurring to a crewman takes on a whole new meaning when the opportunities are significantly increased. Thus, for Space Station there is special emphasis on such areas as bends risk, radiation exposure, and micrometeoroid protection.

1.3.2 Key EVA Design Issues

With the considerations expressed above and with the key applicable lessons learned from the STS EVA experience, several issues emerged from the many considered in the study as having pervasive effects on EVAS design requirements (Figure 1-5).

- EVAS MAINTAINABILITY
- EVAS TECHNOLOGY READINESS
- EVA LSS VOLUME VS EVA TIME AVAILABLE
- SUIT PRESSURE/CABIN PRESSURE RELATIONSHIP AND PRODUCTIVITY EFFECTS
- EVA CREW AUTONOMY
- INTEGRATION OF EVA AS A PROGRAM RESOURCE
- STANDARDIZATION OF TASK INTERFACES

FIGURE 1-5
KEY EVA DESIGN ISSUES

Maintainability is far and away the most important issue in EVAS design and the main reason why the STS EMU will not satisfy SS requirements.

Technology Readiness and risks associated with advanced EVAS technologies must be carefully considered in evaluating their benefits to EVA productivity. An assessment of technology readiness for the EVAS is provided in Section 4 of this report.

EVA LSS Volume vs EVA Time Available. There are several factors combining to drive the EVAS to an overall larger volume. While the STS constraints on volume are not expected to exist for Space

Station, this growth could be controlled by taking advantage of the Station's ability to provide dependent life support capability (i.e. via umbilicals) at remote worksites.

Suit Pressure/Cabin Pressure Relationship and Productivity

Effects. Operating space suits at the pressure levels attendant to a sea level cabin with minimum prebreathe means that unless there is significant improvement in the glove technology the crewman will bear the brunt of having to perform manipulative tasks with very stiff hands. Recent tests have provided insufficient quantifiable data to back up this key feedback from our system operations. Further development efforts must concentrate on improving glove mobility and/or getting the suit pressure down.

EVA Crew Autonomy is an issue which was found to affect many areas of the EVAS and the SS EVA interfaces and accommodations. To maximize the overall productivity of the crew they need to be provided with all the resources to operate independently from the ground, as well as to allow the EVA crew to operate independently from the IV crew. This issue affects EVAS design, including reliability and maintainability aspects, the Data Management System, the Communications System, provisioning, and training and makes a strong case for implementation of IVA automation and EVA robotics.

Integration of EVA as a Program Resource is no less important than integration of other SS user services such as heat transfer, power distribution, pointing accuracy or data handling. This program appears well on its way to achieving this critical perspective and it must be maintained during the SS development.

Finally the Standardization of Task Interfaces must be promoted to increase EVA productivity, enhance the probability of mission success and reduce the overhead burdens associated with performing EVA. If EVA is to be relied upon for SS assembly, maintenance, servicing, and repair and as a resource to be applied to user needs, then properly designed work interfaces are required.

SECTION 2

TASK 1 - MISSION REQUIREMENTS SURVEY

2.1 MISSION AND TASK DETAIL

The study was begun by establishing as much detail as possible about the missions and tasks of the Space Station EVAS. This effort was hindered to some extent by the paucity of reliable information about missions which are 7 to 15 years in the future. Design details were usually sketchy or totally non-existent and quite often the viability of the actual mission was in doubt. Still, enough information existed to derive mission requirements for the Station EVAS.

Several different sources of information were consulted in the search for requirements. For detail on payload servicing missions Langley Data Bases dated March 1984 and May 1985 were consulted. These data bases began in 1991 and 1992, respectively, with the implied assumption that Space Station Initial Operational Capability (IOC) would occur on that initial date. While actual IOC is still unknown, the information derived from the Langley Data Bases should still provide reasonable estimates if referenced to IOC rather than a specific calendar date. As many as possible of the principal investigators or payload sponsors listed in the data bases were questioned. From the latest, perhaps more accurate, Langley Data Base it was determined that, of the 324 total missions, 141 would require some sort of EVA support. These were a mixture of domestic and foreign payloads. All American sponsors were contacted to verify and update the data in the data base. Generally it was found that the information was a sponsor's "best guess" at a very early date on what might fly.

Using the initial data on likely missions for the Space Station EVAS, a list of generic missions was generated which it was believed would describe the things the EVAS would be required to do and which would, by simplifying the analyses and reducing the data to a manageable size, give a clear picture of those EVAS requirements. Fifteen such generic missions were identified. (Figure 2-1) Time estimates were made for each generic mission and these estimates were used to estimate times for each of the missions derived either from the Langley Data Bases or other Space Station documentation. These estimates were then summed to arrive at estimates of EVA time required per year for customer

support. Figure 2-1 presents the results of this process.

1. ALIGNMENT OF XMITTER/RECEIVER ELEMENTS
2. DEPLOY/RETRACT SOLAR ARRAY
3. TRUSS STRUCTURE CONSTRUCTION
4. SATELLITE SERVICE TECHNOLOGY
5. LARGE MODULE MANIPULATION
6. SMALL/MEDIUM MODULE MANIPULATION
7. LARGE MIRROR CONSTRUCTION
8. CONSUMABLES RECHARGE VIA TRANSPORT
9. ORBIT LAUNCH OPERATIONS
10. SUBSATELLITE OPERATIONS
11. SPACE STATION RADIATOR CONSTRUCTION (ORBITER SUPPORTED)
12. ORBITER SUPPORTED LARGE MODULE MANIPULATION
13. ORBITER SUPPORTED TRUSS CONSTRUCTION/DEPLOYMENT
14. RADIATOR CONSTRUCTION-FULL UP SPACE STATION
15. EVA RESCUE

FIGURE 2-1
GENERIC EVA MISSIONS

Our analyses yielded the information that a minimum of slightly more than 1000 manhours of EVA time per year will be required at Station IOC and that within two years approximately 4500 manhours of EVA time will be required per year for all the missions in the Langley Data Base.

To arrive at a reasonable estimate of the actual SS EVA requirements, the data were further analysed as to mission firmness and locations. It was arbitrarily decided to include only those missions which had firmness ratings in the data base of 1,2, and 3, and 20 percent of firmness rating 4. After also removing all polar missions, the results were as depicted in Figure 2-2.

As indicated, 346 manhours of EVA time are estimated to be required in the first year of Space Station operation, increasing to a maximum of 1512 manhours required in the seventh year of Station operation. Two cautions go with these estimates. First, these are only estimates, heavily dependent on guesswork about missions as far as fifteen years in the future. Second, related to the first caveat, a "tail-off" phenomenon exists after the third year of Station operation, indicating that few experimenters and payload sponsors wish to guess about events so far in the future. This yields what is probably a false tail-off in required EVA hours in the latter years covered by the estimates and causes such estimates as exist to consist heavily of firmness 4 missions, yielding a further reduction due to our weighting procedure.

FIRMNESS 1+2+3+20% OF 4

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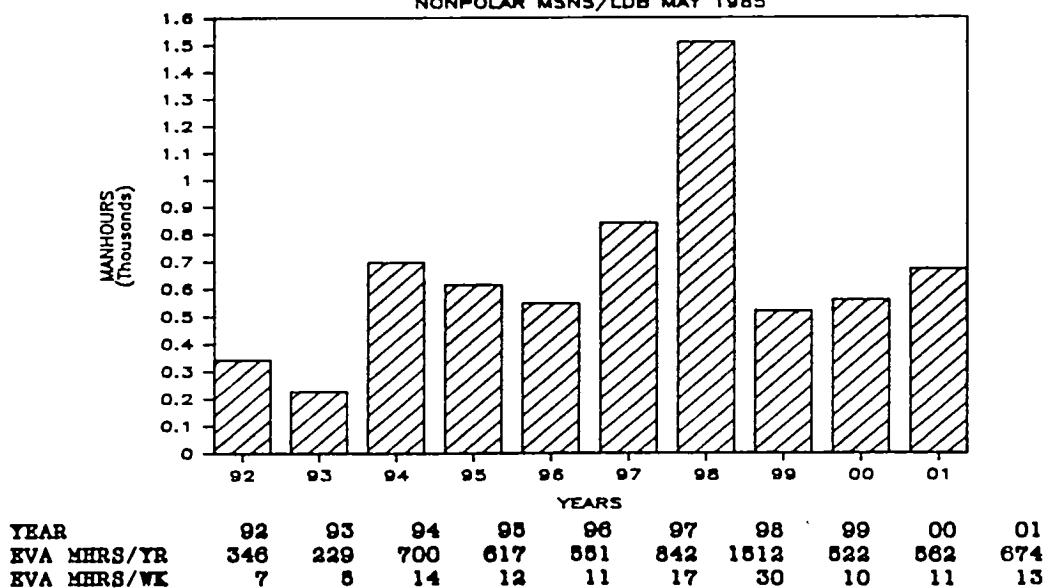


FIGURE 2-2

Estimated EVA Mission Manhour Requirements for Space Station Core

It must also be pointed out that the experience of Skylab and Shuttle indicates that unplanned EVA mission requirements tend to exceed planned requirements by approximately 2 to 1 and for this reason our mission model is thought to be extremely conservative. Regardless of the amount of EVA determined by whatever means, program managers will likely have to allocate EVA crew time as a program resource, with limits determined by crew size, systems design capabilities and overall program priorities. This allocation may then determine which missions may be accommodated. The Functional Requirements Envelope, promulgated by NASA in May 1985 established an allocation of EVA time for users which very coincidentally approximated our user requirements model.

Space Station construction time estimates were also derived by assigning times based on the Generic 15 Missions to construction tasks and plans presented in the Space Station Reference Configuration Description (JSC 19989) and to tasks and plans developed by MDAC Phase B Space Station personnel for the dual-keel configuration. While Station construction may have significant impacts on Space Shuttle EVA support requirements, it does not seem to drive Space Station EVAS requirements, except to the extent of possibly driving the point at which the Station airlock is brought up for assembly with the rest of the Station. Otherwise, there is insufficient data to properly integrate SS construction with the time phased SS EVA mission requirements.

To complete the SS EVA mission model, an assessment of maintenance requirements for the Station was required. With little credible data to support such an analysis, an extrapolation from on-going Phase B studies was made. Various levels of maintenance estimates were derived based on the number of EVA and IVA orbital replaceable units (ORUs) and several values of Mean Time Between Failures (MTBF) were used. An allocation of 1192 EVA manhours per year was made, which resulted from the definition of one manhour MMTR for a properly designed EVA ORU, and reflecting the use of scheduled or planned EVA maintenance to enhance SS maintainability overall. It is important that continuing evaluations be made of SS EVA requirements for maintenance as the systems definition efforts proceed.

Total SS EVA missions requirements, then, are as shown in Figure 2-3. It shows that a minimum requirement of about 1400 manhours per year in the neighborhood of IOC grows to a requirement for approximately 2700 manhours per year at IOC + 6.

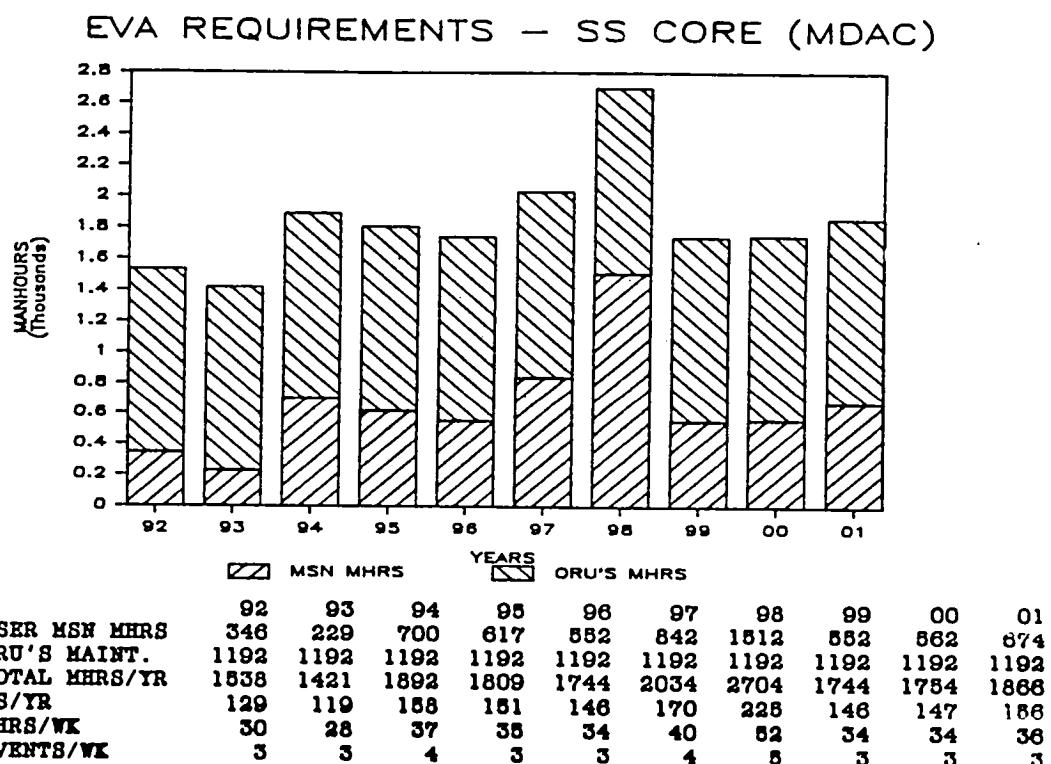


FIGURE 2-3
Total EVA Missions Plus ORU Manhours

2.2 ASSESS REQUIREMENTS AGAINST AN EXISTING DATA BASE

The Space Station EVAS requirements were compared on a task-by-task basis with current Shuttle EVAS capabilities. The general conclusion was that all requirements were well within the capabilities of a suited crewmember to perform. That is, no specific EVAS hardware requirements or capabilities were driven by the information on missions and tasks which were obtained. When the EVAS capabilities were considered in light of likely 90 day mission models, two basic problem areas were identified.

First, EVA operational impacts to Shuttle flights could not be tolerated on the Space Station. This was particularly true in the case of three specific impacts. The frequent large pressure changes in cabin atmosphere incurred as a normal part of Shuttle EVA's could not be tolerated on the Station with its sensitive scientific experiments. Similarly, all Station operations could not be driven by EVA support requirements as they are on the Shuttle. EVA must be a routine, minimum impact part of day-to-day Station operations, not a special case requiring maximum attention from all hands. Finally, the heavy task-specific pre-launch training encountered in preparing Shuttle crews for EVA tasks will not be possible for Station crewmembers. Too many nominal and far too many contingency tasks are possible during the course of a 90 day mission to specifically train for them on the ground prior to flight. These operational impacts, then, require different handling on Space Station than they did on Shuttle.

The second major difficulty arising from considering the entire EVA mission model instead of just individual tasks is the problem of EVAS maintenance. Currently, all EVA equipment undergoes a maintenance cycle after every flight. For most equipment this involves an extensive tear-down, test, and component replacement with subsequent reassembly and complicated test and certification for re-flight. Such procedures are not possible on the Space Station due to time, personnel, operational, and material limitations. A stronger emphasis on maintainability in the design philosophy is thus called for, leading to an EVAS which requires very little maintenance per hour of operation, fails in a safe manner when it does fail, and which can be easily and quickly repaired or serviced when required.

The actual hardware impacts associated with these findings will be discussed in depth in the detailed study report, but the above considerations constitute the drivers for the requirements embodied therein.

2.3 ANCILLARY EQUIPMENT REQUIREMENTS

Partly as a result of the assessment of EVAS requirements against an existing database of EVA experience and knowledge, and partly as a result of a dedicated analysis effort based on the Generic 15 Missions and the various mission models, a list of approximately 120 pieces of EVA ancillary equipment was derived.

Two broad categories of equipment, Generic Equipment and Special Equipment were included in the list. Generic Equipment would be provided as a normal part of the EVAS in standard equipment/tool kits, arranged most likely into a nominal tool kit and supplementary kits. Special Equipment would be provided by individual payload sponsors as required to service their particular payloads, assuming that equipment from the generic kits would not suffice.

It should be noted that the ancillary equipment list currently contains both off-the-shelf hardware and hardware requiring various amounts of development. Often a significant portion of such hardware development consists solely of making an otherwise off-the-shelf item compatible with EVA operations. As a general guideline in EVA operations design, it is desirable to minimize new hardware development by avoiding the use of Special Equipment and by maximizing the use of the Generic Equipment already provided. However, the primary emphasis should be on minimizing all loose equipment (Generic or Special) by proper design of the subject equipment's interface with the EVAS. For instance, use of captured butterfly latches on access ports is much to be preferred over the use of bolts or screws requiring wrenches or screwdrivers. While wrenches and screwdrivers are very much off-the-shelf equipment, the butterfly latch dispenses with all loose equipment (insofar as it's own operation is concerned) and is therefore better than bolts and screws requiring tools to operate them.

2.4 DOD EVA REQUIREMENTS

DOD EVA requirements were coordinated through the USAF Space Division in El Segundo, California. The DOD identified no mission specific EVA requirements, but instead, expressed twelve "concerns" which must be addressed by the EVAS in order for it to be usable on defense-related missions. Of these concerns eleven were already included as considerations in this study. The twelfth concern - an expressed desire for a two minute EMU don/doff capability - was not a requirement for the Space Station EVAS.

- IMPROVED MOBILITY
- MAINTAINABILITY
- RADIATION PROTECTION
- STATIC CHARGING HAZARD
- IMMEDIATE EVA CAPABILITY
- CONTAMINATION CONTROL
- SIZING
- HEADS-UP DISPLAY
- MICROMeteoroid PROTECTION
- COMFORT
- CONTINGENCY TRANSLATION AIDS
- RAPID DONNING/DOFFING

FIGURE 2-4
DOD EVA SYSTEMS ISSUES

CONCLUSIONS

The central conclusion of the mission requirement survey is that, while mission data base detail is insufficient for accurate determination of specific task requirements, all EVA mission requirements can be described in terms of the Generic 15 EVA Missions. Because of this, it is felt that the capability to accomplish the 15 Generic EVA Missions is mandatory and should be the focus of future work until such time as greater mission specific detail is available.

A second key conclusion is that, while individual tasks can be accomplished by any suited crewmember, the current Shuttle EVAS would not be satisfactory when examined in the light of the overall mission model. Current EVAS impacts on Shuttle operations could not be tolerated on the Space Station, both in the area of EVA operations and in the area of EVAS servicing and maintenance. Therefore, a much improved EVA System must be provided for the Space Station.

A final conclusion, based on the overall mission model, is that, while a two man EVA crew will suffice for the first years of Space Station operations, within four to six years of Station IOC a four man EVA crew will be required.

RECOMMENDATIONS

1. The EVAS should be designed so that EVA time is crew limited, not hardware limited.
2. The capability should be developed to perform all 15 Generic Missions including development of all Generic Ancillary Equipment.
3. The EVAS must be maintainable on-orbit with continuous operations for 90 days on a 50% duty cycle as a minimum.

4. All payload sponsors should be made familiar with the JSC 10615A document and be encouraged to use it in their design efforts. For time estimate purposes, they should be made familiar with the Generic 15 Missions.

5. All payload sponsors should be provided with a Generic Tool Kit description and a Specialized Tool Kit description. They should be encouraged to use a design requiring minimal loose equipment with such equipment as required being chosen from the Generic Tool Kit if possible. They should be encouraged to identify any required specialized tools as quickly as possible.

SECTION 3

TASK 2 - EVAS BASELINE DESIGN REQUIREMENTS AND CRITERIA

3.1 OPERATIONS

In order to develop realistic design requirements, a general understanding of EVA operations is necessary. EVA by its very nature provides the flexibility to change the way we operate in space on a day-to-day basis, but certain functions are required to be performed regardless. The key elements of any EVA operation from a mature Space Station are:

3.1.1 PLANNING/SCHEDULING: EVA tasks to be performed are scheduled by the master crew scheduling system, along with any other (IV) tasks to be performed for a particular day. Tasks are prioritized according to criticality, proximity to one another, launch windows, etc., then a group of tasks is selected to be performed in the course of an EVA event. EVA is nominally scheduled to be conducted during the 9 orbits/day which do not pass through the South Atlantic Anomaly in the Van Allen radiation belts. At least two crewmembers on each shift have been trained to perform EVA, allowing mission planners maximum flexibility.

3.1.2 EVAS HARDWARE: Each EVA crewmember normally is assigned an Extravehicular Mobility Unit (EMU) consisting of a Life Support System and Crew Enclosure, and is responsible to insure that all required checks have been performed on his unit prior to EVA, whether manually or automatically. On-orbit resizing capability is required in order to permit changes in crewmember/EMU assignment, changes in sizing preference, and maintainability (modularity) of the EMU crew enclosure joints, but resizing is not normally accomplished on a routine basis. Four complete EMUs (1/crewmember, 2 crewmembers/shift) will provide the flexibility and redundancy needed to support the number of EVA hours predicted.

3.1.3 TYPICAL SCENARIO

3.1.3.1 PRE-EVA: Donning of cooling garment and waste collection device(s) is not discussed here; we have assumed that this would take place in the crewmember's personal quarters, much as a workman on earth decides when he gets up whether to wear work clothes or a business suit for a particular day's activities. The day's mission is reviewed among the crew and/or

ground support personnel. Checks equivalent to preflight inspection of an aircraft are performed on the EMU. These checks consist primarily of confirmation of completion of servicing (battery recharge, CO₂ media regeneration or replacement, heat sink regeneration or recharge, and oxygen recharge), followed by a visual inspection of the hardware. Each EMU has an associated "logbook" in the Station Data Management System (DMS) which keeps track of accumulated time on the EMU components as well as any minor anomalies which do not preclude system operation, but may possibly cause degraded performance of one or more subsystems. This "logbook" is also reviewed as a part of the checks. Functional checks are performed in conjunction with system donning and activation, assuming no major maintenance has been performed since the last use. If any of these checks reveal a condition which cannot be corrected on the spot, the EVA is postponed unless it is time-critical, in which case a spare EMU is utilized for that particular EVA event, with the failed unit being restored to an operational condition in one duty cycle or less (approximately two days initially, one day or perhaps even one shift as the tempo of operations picks up in later years).

3.1.3.2 EVA: The conduct of the EVA consists of some amount of overhead--translation to worksite, trash stowage, etc.--and performance of some combination of the generic EVA tasks/missions identified in section 2 for a total time at reduced pressure up to 7 hours, with up to 6 hours of that being dedicated to useful EVA tasks. (An additional hour of reserve capacity is available from the Life Support System, but this capability is not normally used except in an emergency.) Translation requirements can be satisfied by a number of approaches (hand-over-hand, propulsion, "dumbwaiter" or trolley concepts, etc.); flexibility can be most enhanced by not precluding any of these methods. For example, a trolley is likely the most efficient means of translation along a keel, while access to solar panels or the like for inspection, and especially rendezvous with/retrieval of free-fliers will require some sort of maneuvering propulsion. Upon arrival at the worksite, restraint is required for the crewmember and for any tools or other ancillary equipment in use. Permanent workstations will be provided in areas of intensive EVA activity, probably along with Station services such as power, hardline communications, and cooling. Some sort of portable, temporary workstation will be required which attaches to most any part of the Station, probably to the truss structure, for use in areas which do not have prepared worksites.

3.1.3.3 POST-EVA: After repressurization of the airlock and EMU doffing, the crewmember initiates recharge and performs a visual inspection of the EMU. The recharge systems located in the airlock automatically shut off upon completion of the recharge. Optionally, this recharge can be accomplished by module replacement to enable rapid turnaround of the EVAs.

3.1.4 EVA SYSTEMS AND TASK TRAINING

Considering the sheer number of EVA hours required annually and the necessity of devising operational techniques and procedures between infrequent Shuttle flights, the impact of extensive mission-specific ground training associated with STS EVA clearly cannot be tolerated for Station operations. The following training philosophy is therefore recommended.

3.1.4.1 GENERIC TRAINING (ground): EVA crewmembers receive training roughly equivalent to that provided for STS flights without a planned EVA. This is currently broken into two distinct areas:

- o System operation fundamentals such as activation and troubleshooting of the Primary Life Support Subsystem (PLSS), donning/doffing of the Space Suit Assembly (SSA), and activation, piloting techniques and troubleshooting of the Manned Maneuvering Unit (MMU). Normal servicing and maintenance tasks are taught as a logical outgrowth of this training.
- o Performance of certain identified contingency EVA tasks required for safe return of the Orbiter after a given set of failures. Corrective actions for these failures, however credible, provide practice in the required basic skills such as position maintenance, translation, teamwork, and tether protocols, as well as familiarization with mobility limitations associated with pressure suits.

3.1.4.2 TASK SPECIFIC TRAINING: This training will be conducted on-orbit, primarily by the use of OJT. Unusually complex tasks may require special augmentation via video/CAI presentations, but for the most part rely on an awareness of EVA considerations during the design of the component/payload or during mission planning to enable application of generic training to the particular task.

3.1.4.3 RECURRENT TRAINING: Emergency procedures and system refresher training will need to be conducted regularly in order to insure maximum crewmember proficiency and safety. This is partially a subset of task-specific training, in that rescue of an incapacitated EVA crewmember, for instance, differs only in criticality, not in task performance, from the translation of any large object or module. System emergency procedures training could best be accomplished by use of the EVAS DMS in concert with the Station DMS to simulate various system failures.

3.1.5 EVA SYSTEMS MAINTENANCE

On-orbit maintenance of the EVAS is, for all practical purposes, completely new ground for the U. S. space program. The relatively short duration of missions to date, along with the relatively small number of EVA hours required and the philosophy that EVA is a backup to other methods of mission accomplishment,

have relegated on-orbit maintainability to the status of an unnecessary luxury, one that we could ill afford in an era of decreasing NASA budgets. With the dependence expected to rightfully be placed on EVA for mission accomplishment in the Station environment, on-orbit maintainability ceases to be a luxury and becomes instead an absolute necessity. Incorporation of maintainability features in the EVAS at the outset not only increases the probability of success for any payload exterior to the pressurized compartments of the Station, but provides a built-in capability to upgrade the system as will inevitably be required after well-meaning (and in all likelihood, necessary) budget cutting at the front end of the program forces acceptance of a less than optimum initial configuration.

3.1.5.1 SCHEDULED MAINTENANCE: For STS, scheduled maintenance has consisted of approximately 3000 hours of ground turnaround between each mission. This will have to be reduced to no more than annual refurbishment of systems, and ideally to repairing only inoperative components. There is no apparent reason why the hardware should not continue to operate indefinitely, just as aircraft continue to provide reliable service after many years of operation.

3.1.5.2 UNSCHEDULED MAINTENANCE: Provisions will have to be made aboard the Station to troubleshoot the EVAS and to isolate failures to the ORU level. Definition of this level is premature at this point, as it is circularly dependent on system design, which in turn depends on ORU level definition. This iterative process is best accomplished during the preliminary design phase. Considerations will include tool requirements for disassembly of components, cleanliness requirements, crew training, and many others. As a general rule, design of any system should not preclude any subcomponent being designated as an ORU unless this unnecessarily complicates design or increases cost (procurement or operations).

3.1.5.3 MAINTENANCE DOCUMENTATION:

The Documentation System ("logbooks") has access terminals at all maintenance locations (primarily the airlock).

The EVAS components (crew enclosure, life support system, propulsion system, and support equipment) are subdivided into ORUs, at which level all maintenance documentation will be recorded.

3.2 EVA SYSTEMS REQUIREMENTS

The basic configuration of the EVAS is driven by the environment. That is, any configuration developed will have to provide life support services, environmental protection, and probably propulsion.

The configuration and system sizing are driven by operational considerations. Due to the lack of detailed definition of missions, we feel that the best approach is to try to maximize the advantage from having a man present, which means enhancing his flexibility at every opportunity. In doing this, several overall EVAS issues come to light:

- MAINTAINABILITY--The elements of maintainability (modularity and accessibility) go further toward permitting design flexibility than any other concept. That is, any ORU that can be removed and replaced during maintenance can just as easily be replaced by an uprated version for growth or a less advanced system for fall-back in the event of technical or funding problems in advancing technology.
- SUBSYSTEM FUNCTIONAL INTEGRATION--Closely related to maintainability, frequently competing. Should be minimized in favor of maintainability. NOTE: This does not apply to physical integration such as putting the radio in the backpack, rather to such concepts as tying the humidity control system to the feedwater system as in the STS EMU PLSS. While this effectively minimized the PLSS volume as required by STS considerations, it precludes upgrade of one of these systems without a complete system redesign.
- AUTONOMY--Every opportunity to provide autonomy of the Station from the ground or the EVA crewmember from the Station should be capitalized upon, thus providing a host of operational (flexibility) benefits.
- ACCEPTABLE PHYSIOLOGICAL RISK--Since so little is known about the physiology of decompression sickness, we feel the best approach is to not try to determine some boundary level of denitrogenation, rather a cabin/suit pressure ratio should be adopted which negates the need for prebreathe. (According to current thinking, this means $R = 1.22$ or less, where R is the ratio of alveolar nitrogen to the final suit pressure.) For the sake of EVA productivity, this combination should be as low as possible consistent with fire hazards, experiments, etc. From an EVA standpoint, a cabin pressure of 70 kPa (10.2 psi) with 30% O₂, along with an EVAS operating pressure of 40 kPa (5.8 psi) would seem to be the optimum.

- NOMINAL AND MAXIMUM LENGTH OF EVA--While longer EVA duration capability means a larger LSS, the overhead associated with getting outside on a "per event" basis dictates that the system be sized according to practical upper size limits and physiological (fatigue) considerations.

Different disciplines have a different view of this. From an operational standpoint, we should provide 6 hours per crewmember per day available to users. From an equipment design standpoint, 8 total hours of life support available including reserve. From a logistics standpoint, 3 two-man EVA events per week.

- REDUNDANCY--No single, credible failure should result in the loss of a critical function (though it may possibly result in function degradation and/or premature termination of EVA).

In summary, the correct approach to defining design requirements for a productive EVAS is to strive to provide the maximum flexibility in order to enable future operations planners, design engineers, and most of all EVA crewmembers to apply the advantages of human presence with minimum restrictions. EVAS requirements were developed based on this premise, and are summarized in Sections 3.2.1 through 3.2.12. Discussions of rationale for each requirement are contained in the detailed study report.

3.2.1 LIFE SUPPORT REQUIREMENTS

The Life Support System (LSS) must provide the following functions in Low Earth Orbit (LEO) space vacuum during performance of tasks identified in Section 2.

- PRESSURIZATION/PRESSURE CONTROL
 - ADJUSTABLE PRESSURE FROM 30-66 kPa (4.3-9.5 psi)
 - REDUNDANT REGULATORS
 - EMERGENCY MANUAL BACKUP
- BREATHING OXYGEN--TOTAL 6 KG
 - 6 HOURS OF USEFUL WORK @ 300 W (1000 BTU/HR) AVG
 - 2 HOURS OF COMBINATION OVERHEAD/RESERVE @ 300 W
 - 45 MIN OF CONTINGENCY OPERATIONS W/ 6 KG/HR LEAK

3.2.1 LIFE SUPPORT REQUIREMENTS (continued)

0 ATMOSPHERE REVITALIZATION

- 0 CO₂: SIMILAR TO SHUTTLE REQUIREMENTS--PERMIT HIGHER LEVEL DURING HIGH METABOLIC ACTIVITY AND LATE IN EVA
- 0 HUMIDITY: 40-70% RELATIVE HUMIDITY, MAX 90%
- 0 TRACE CONTAMINATES: IDENTICAL TO SHUTTLE REQUIREMENTS
- 0 THERMAL CONTROL--Collect, store, and/or reject heat.
 - 0 100-600 WATTS (340-2000 BTU/HR)
 - 0 NO OVERHEATING BELOW 450 W
 - 0 AUTO CONTROL DESIRABLE

3.2.2 ENVIRONMENTAL PROTECTION REQUIREMENTS

The EVA crewmember and EVAS must be protected from the surrounding environment.

0 RADIATION

0 IONIZING

0 PROTON

- 0 MAINTAIN TOTAL MISSION DOSE @ ACCEPTABLE LEVELS
- 0 SCHEDULE ALL NON-EMERGENCY EVA AROUND SAA

0 RF

- 0 CONTROL OPERATIONALLY

0 NON-IONIZING: PROTECT EYES, HELMET FROM UV

0 MECHANICAL DANGERS

- 0 MICROMETEOROIDS/SPACE DEBRIS > 95% PROB OF NO PUNCTURE BASED ON DEBRIS MODEL
- 0 SHARP CORNER/EDGE SAME AS SHUTTLE SINCE STS EMU USED FOR CONSTRUCTION

0 ATOMIC OXYGEN: CONTROL WITH MATERIALS SELECTION/SHIELDING

3.2.2 ENVIRONMENTAL PROTECTION REQUIREMENTS (continued)

0 STATIC CHARGING

- 0 CREWMEMBER: LEVELS DO NOT PRESENT A DIRECT THREAT
- 0 EVAS/PAYLOAD: PROPERLY GROUND, SHIELD ALL ELECTRONICS; USE GROUND STRAP WHEN APPROACHING PAYLOADS

3.2.3 MOBILITY/ANTHROPOMETRIC SIZING REQUIREMENTS

Mobility considerations produce a requirement for an anthropomorphic crew enclosure with maximum torque and minimum joint range equivalent to a Shuttle EMU at 30 kPa (4.3 psi).

Range of crew size to be accommodated should be specified so as to fit the largest possible percentage of the target population with the minimum number of components. Attempts to fit an arbitrarily defined range of male and female percentiles for STS resulted in a system which cost far too much, compromised fit for all but a few, and ultimately failed to fit the specified range due to the technology limitations of building gloves for the small end of the anthropometric range while retaining sufficient mobility to allow the crewmember to perform useful tasks.

3.2.4 COMMUNICATIONS REQUIREMENTS

- 0 ALL RF LINKS REQUIRE ENCRYPTION CAPABILITY
- 0 VOICE
 - 0 FULL DUPLEX BETWEEN ALL PARTIES AT ALL TIMES
 - 0 DESELECTION OF STATIONS ON NET CAPABILITY FOR EVA CREWMEMBERS
 - 0 CONSIDERED SUBSET OF DATA COMMUNICATIONS SINCE DIGITAL SYSTEM IS ANTICIPATED
- 0 DATA
 - 0 SS --> EVAS
 - 0 RELATIVE STATE VECTOR (1/SECOND) DURING UNTETHERED OPERATIONS
 - 0 PROCEDURAL TEXT AND GRAPHICS (1 SCREEN/5 SECONDS)
 - 0 EVAS --> SS
 - 0 COMPLETE SYSTEM STATUS (1/SECOND)
 - 0 CONTINUOUS CARRIER ("KEEP-ALIVE")

3.2.4 COMMUNICATIONS REQUIREMENTS (continued)

o VIDEO

- o NOMINAL ATTACHED OPS COVERED BY STATION CCTV SYSTEM
- o STATION --> EVAS
 - o ONE SCREEN/5 SECONDS
 - o HARDLINE CONNECTOR ON EVAS (FULL MOTION FROM STATION, PREVIEW CAMERA TRANSMISSIONS)
- o EVAS --> STATION
 - o FULL-MOTION REQUIRED DURING EEU FREE FLIGHT

3.2.5 DATA MANAGEMENT REQUIREMENTS

o I/O DATA HANDLING FUNCTION

- o PROVIDE INTERFACES TO EVA CREWMEMBER, EVAS DISPLAY, EVAS SYSTEMS, EVAS COMMUNICATIONS SYSTEM
- o VALIDATE RECEIVED DATA ACCORDING TO CRITICALITY

o SYSTEMS MANAGEMENT FUNCTION

- o SAMPLE ALL BIO, EMU, EEU INSTRUMENTATION, DISTRIBUTE DATA
- o DETERMINE HEALTH, MISSION STATUS, ISSUE C & W
- o MANAGE DISPLAYS (SOURCE, TYPE)
- o EEU GUIDANCE AND CONTROL

o APPLICATIONS PROGRAMS

- o FIRMWARE REQUIRED FOR SAFETY-CRITICAL FUNCTIONS
- o STANDARDS/SPECS SIMILAR AS POSSIBLE TO THOSE FOR SS INTERGRATED DMS
- o STANDARDIZED CREWMEMBER INTERFACE

3.2.6 MANEUVERING PROPULSION REQUIREMENTS

- MMU-CLASS VEHICLE (EEU) REQUIRED FOR CREWMEMBER RESCUE SCENARIO, HIGHLY DESIRABLE FOR ROUTINE MISSION OPERATIONS
- REMAINDER OF REQUIREMENTS DEVELOPED ASSUMING EEU WOULD BE DEVELOPED AND BUILT
 - OMV-CLASS VEHICLE (TUG) HIGHLY DESIRABLE FOR LARGE OBJECT MANIPULATION
 - COLD GASEOUS NITROGEN FOR PROPELLANT EXCEPT FOR REMOTE TUG OPS
 - 50 M/SEC (150 FT/SEC) DELTA-V REQUIRED FOR EEU
 - SAME ACCELERATION (TRANSLATIONAL AND ROTATIONAL) AS SHUTTLE MMU
 - REDUNDANT PROPULSION AND CONTROL SYSTEMS AS ON SHUTTLE MMU
 - NAVIGATION/TARGETING INFORMATION FOR RENDEZVOUS W/ CEP < 10 M AT < 2 KM
 - AAH CAPABILITY W/ SELECTABLE INHIBIT OF UP TO 2 AXES
 - SELECTABLE CG OFFSET COMPENSATION
 - ATTACHMENT PROVISIONS FOR ROBOTIC/TELEOPERATOR CONTROL
 - UNIVERSAL GRAPPLE FIXTURE
 - CREWMEMBER RESCUE INTERFACE FOR CREWMEMBER W/ OR W/O EEU
 - VARIABLE THRUSTER SELECT LOGIC TO MINIMIZE PLUME IMPINGEMENT
 - AUTO SERVICING W/ MINIMUM CREWMEMBER INTERVENTION

3.2.7 CREWMEMBER SUPPORT REQUIREMENTS

- HAND-IN CAPABILITY HIGHLY DESIRABLE TO ENHANCE ALL FUNCTIONS
- 750 CALORIES OF FOOD FOR EVA CONSUMPTION
- 1.2 LITERS (40 OZ) OF WATER FOR EVA CONSUMPTION
- WASTE MANAGEMENT
 - HYGIENICALLY COLLECT 1.5 LITERS (51 OZ) OF URINE
 - FECAL/VOMITUS CONTROL NOMINALLY ACCOMPLISHED THROUGH DIET AND PERSONAL HABITS

3.2.8 MAINTENANCE/MAINTAINABILITY REQUIREMENTS

- MODULAR DESIGN W/ EASY ACCESS, QUICK DISCONNECTS FOR FLUID AND ELECTRICAL CONNECTORS
- MINIMIZE REQUIREMENT FOR PERIODIC MAINTENANCE AND TESTING--MAINTAIN ON CONDITION
- FAIL-SAFE DESIGN ALLOWING SAFE RETURN TO A PRESSURIZED ENVIRONMENT AFTER COMPONENT FAILURE
- IV MAINTENANCE WORKSTATION WITH APPROPRIATE RESTRAINT/POSITION AIDS AND FLUID, ELECTRICAL, AND ELECTRONIC INTERFACES
- EVA MAINTENANCE STAND FOR EEU, INCLUDING PROVISIONS FOR PROPELLANT VENTING IN THE EVENT THE EEU OR SOME COMPONENT THEREOF MUST BE BROUGHT INSIDE

3.2.9 SERVICING REQUIREMENTS

- ROUTINE SERVICING AUTOMATED TO MAXIMUM EXTENT PRACTICAL
- IF REGENERATIVE LSS SYSTEMS USED, IN-PLACE REGENERATION IS DESIRABLE

3.2.10 LOGISTICS REQUIREMENTS

- SUFFICIENT CONSUMABLES AND SPARE PARTS FOR 120 DAYS W/ THREE TWO-MAN EIGHT-HOUR EVAs/WEEK
- STORAGE CAPABILITY FOR ONE YEAR'S SUPPLY OF EEU PROPELLANT HIGHLY DESIRABLE
- MINIMIZE QUANTITIES OF SPARE PARTS REQUIRED THROUGH USE OF RUGGED, HIGH-RELIABILITY PARTS
- MINIMIZE REQUIREMENT FOR TOOLS (ESPECIALLY UNIQUE TOOLS)

3.2.11 OPERATIONAL LIFE REQUIREMENTS

- MINIMUM ONE YEAR ON-ORBIT BETWEEN GROUND RESERVICING
- MINIMIZING COMPONENT MASS SHOULD BE SECONDARY TO SIMPLICITY AND RUGGEDNESS
- OPERATIONAL CYCLES SHOULD BE MINIMIZED (E.G., CHECKOUT IN CONJUNCTION W/ NORMAL DONNING AND ACTIVATION)

3.2.12 EXTERNAL CONFIGURATION REQUIREMENTS

- ANTHROPOMORPHIC CREW ENCLOSURE
- EMU SIZED FOR 95th PERCENTILE CREWMEMBER SHALL PASS THROUGH SHUTTLE AIRLOCK HATCH
- EEU SHALL ACCOMMODATE CREWMEMBER IN SHUTTLE EMU

SECTION 4

TASK 1 - SPACE STATION/EVA SYSTEM INTERFACE REQUIREMENTS AND EVA ACCOMMODATIONS

The Space Station/EVAS interface requirements fall into eight different categories:

1. Atmosphere Composition/Pressure
2. Communications
3. Data Management
4. Logistics
5. Safe Haven
6. SS Exterior Requirements
7. SS Interior Requirements
8. SS Airlock

4.1 ATMOSPHERE COMPOSITION AND PRESSURE

Several issues impact the choice of Station cabin atmosphere and pressure. EMU pressure should be as low as possible to provide the least productivity impact due to glove and suit joint mobility impairment or to pre-breathe requirements. Feasible maximum suit pressures drive feasible maximum cabin pressures because of the necessity for denitrogenation as the delta between the two increases. Figure 4-1 illustrates the relationship between EMU and cabin pressure with the area inside the lines defining possible combinations of pressures based on various assumptions. The parameter R is defined as the ratio of partial pressure of nitrogen in the crewmember's tissues to final (EMU) pressure. Note that zero pre-breathe is assumed, which means that, according to current medical research, an R of 1.22 and no higher is desired to prevent an occurrence of bends. The glove mobility limit line indicates the highest pressure at which current technology provides reasonable glove mobility.

Based on this analysis, a Station cabin pressure of 10.2 psi would be recommended, which together with an R value of 1.22 and a suit pressure of 6 psi would give acceptable EVAS performance with no pre-breathe. However, the Phase B programmatic decision has been made, due to other, global, Space Station considerations, to set cabin atmosphere at 14.7 psi Earth normal. This shifts all impacts, then, to the EVAS, pushing us beyond current glove technology for high pressure mobility or beyond acceptable bends risk without denitrogenation.

As Figure 4-1 indicates, due to the 14.7 psi cabin atmosphere either a high technological risk is incurred by requiring a suit pressure of 9.5 psi (with no pre-breathe), or productivity impacts are generated by requiring pre-breathe to achieve the lower suit pressure. The option of higher R values on a regular basis is not recommended due to increased crewmember risk of bends. The possible requirement for pre-breathe could force an impact on the Space Station by generating a further requirement for an intermediate pressure in the EVA prep area.

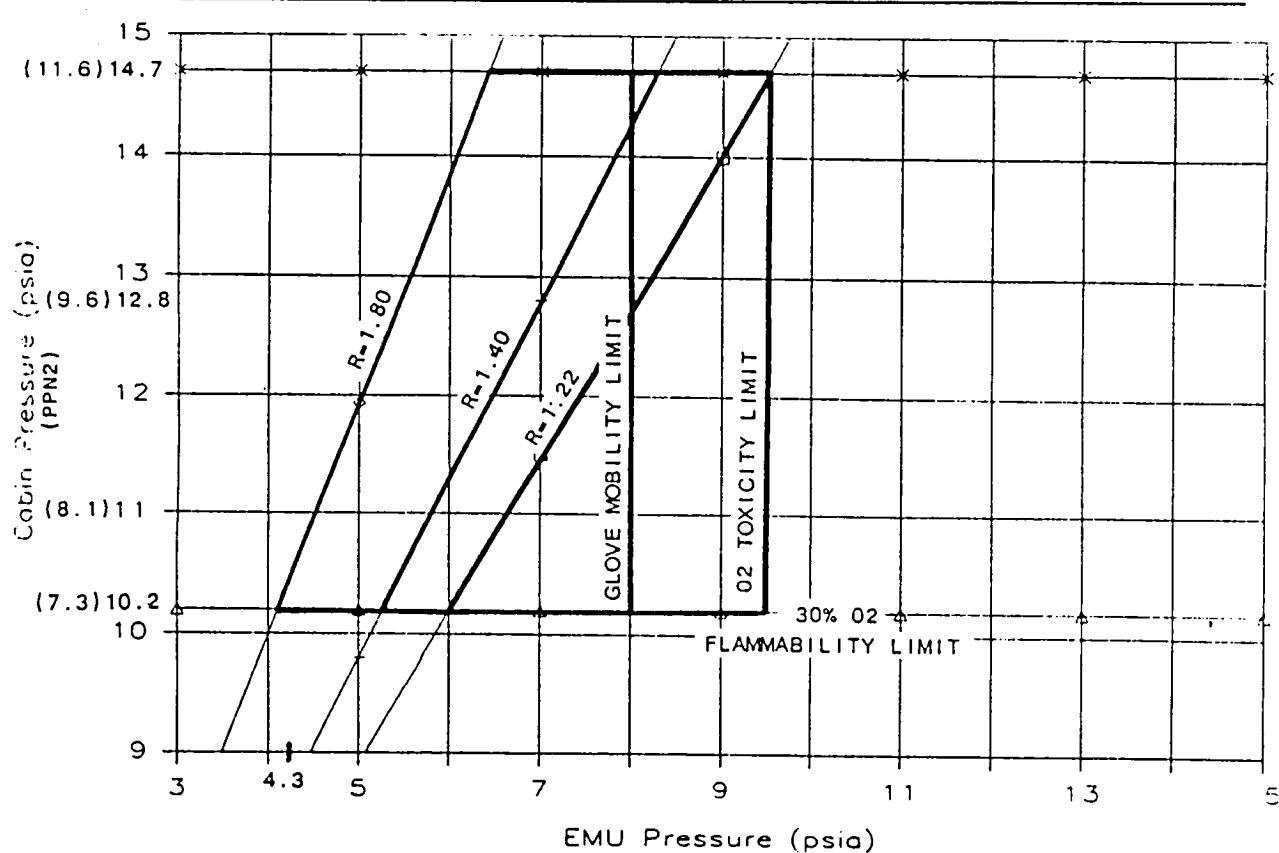


FIGURE 4-1
CABIN/EMU PRESS FOR ZERO P/B

4.2 COMMUNICATIONS

Three types of communication are desired to support EVA operations. They are:

1. Full Duplex Voice Communications
2. Data Uplink/Downlink
3. Video Uplink/Downlink

where uplink/downlink refers to Station to EVAS communications.

Full duplex voice communications would have to be provided for up to four EVA crewmembers simultaneously with the added provision to allow different teams of crew members, both IV and EV, to carry on separate conversations without interference from the other team.

Data uplink/downlink would consist of communication of system status data, alarms, and crew health data and possibly navigation information for a free-flying crewmember. Note that information would travel both ways, from Station to EVAS and vice-versa.

Video communications would provide freeze frame television to the EV crewmembers for transmission of procedural/task aids, and full motion television from the crewmember to the Station for worksite/task data to the Station and ground.

All issues associated with the Communications interface are straightforward design issues such as selection of the method of navigation of a free-flyer or degree of integration of the EVAS communications system with the station communications system. A list of all issues is presented in Figure 4-2.

1. FULL INTERGRATION OF EVAS COMM. WITH STATION COMM.
2. DIRECTIONALITY OF SIGNAL
3. POWER REQUIREMENTS
4. COMPATIBILITY WITH SHUTTLE
5. MAINTENANCE REQUIREMENTS
6. METHOD OF NAVIGATION

FIGURE 4-2
EVA/SS COMMUNICATIONS ISSUES

4.3 DATA MANAGEMENT SYSTEM

The Space Station/EVAS Data Management System (DMS) would be responsible for all data handling and for the associated data systems management. The EVAS and associated EVAS DMS should appear to the Station DMS as merely another user with, possibly, some peculiar Input/Output requirements.

The DMS would be responsible for input/output data handling, interfacing the Station and EVAS processors to the full duplex telemetry system.

The DMS would be responsible for monitoring it's own systems and would also be responsible for monitoring EVA systems, providing EVAS monitoring and control (including alarms and procedures), free-flyer navigation and targeting information, and general displays management. The DMS could act as residence for an EVA monitor expert system.

Issues associated with the DMS are questions of allocation of functions to the EVAS or Station DMS, and questions of allocation of functions to software or firmware.

4.4 LOGISTICS

Upon analysis, five general EVA logistics requirements categories were discovered. These are:

1. Scheduled Maintenance Items
2. Regenerable EVAS ORUs to Support Quick Turnaround
3. Single Use and/or Low MTBF Items
4. Select Damage Prone Items
5. Select Random Failure Items

These group into two classes of resupply items:

1. On-Board Spares - One Time Delivery, Replenish as Required
2. Resupply Items - Resupply Every 90 Days

After determining initial quantities of EVAS items from operational considerations and the mission model, spares and resupply cycle data were derived from STS experience and extrapolations from technology development programs. Tables such as Table 4-1 were derived for each major EVAS end-item and overall logistics requirements were determined as shown in Table 4-2.

ON-ORBIT EMU SPARES - One time delivery; replenish as required

ITEM	QUANTITY	MASS kg (lbm)	VOL. liters (Ft3)
EMU LSS	2	378 (834)	382 (13.5)
SCU	2	10 (22)	57 (2.0)
Phase Change Heat Exchanger	2	20 (43)	28 (1.0)
CO2 Removal Canister	2	98 (216)	
CWS			

TABLE 4-1
PROJECTED EMU SPARES REQUIREMENTS

	MASS (KG)	VOL (LITERS)
ON ORBIT EMU SPARES Resupply as required	520	555
EMU RESUPPLY 90 DAYS	414.5	537
ON ORBIT SERVICE EQUIPMENT SPARES Resupply as required	47.2	46.9
SERVICE EQUIPMENT RESUPPLY	0.3	6
EEU SPARES Resupply as required	190.6	125.1
ANCILLARY EQUIPMENT SPARES	54.1	361.6

TABLE 4-2
LOGISTICS REQUIREMENTS SUMMARY

Logistics issues stem from the uncertainty currently present in all EVAS designs. ORU definition is configuration dependent and actual MTBFs will drive sparing provisions, as will the maintenance philosophy adopted and implemented. Additionally, all EVAS use models, especially the EEU use model, are fairly soft.

4.5 EVA SAFETY HAVEN

The EVA Safety Haven would have two practical uses:

1. As a shielded refuge from harmful radiation environments
2. As a pressurized refuge in cases of EVA crew emergency at a remote worksite requiring rapid pressurization

Two basic radiation threats present themselves to the EVA crewmember at LEO: the South Atlantic Anomaly in the Van Allen belts and sudden intense solar flares. The South Atlantic Anomaly is a downward bulge of the Van Allen belts towards the surface of the earth which subjects any unshielded crewmember passing through it to higher than normal radiation fluxes. Over a period of 90 days, the expected average crew stay time, these exposures could add up to harmful levels. While a safe haven could be used to shield the EVA crew member for the 15 minutes of a pass through the Anomaly, the problem can be avoided entirely simply by scheduling the EVA to coincide with orbits which miss the SAA. This means that the EVA crew shift would have to be changed, say from first to second shift, as orbital precession moved SAA passes into EVA periods. This is preferred to use of a safety haven.

Sudden intense solar flares could also pose a threat to the EVA crew. While an EVA safety haven could be used to protect them, in all cases sufficient warning of the arrival of a flare (at least 8 minutes) should exist to allow the crew to return to the Station interior and seek shelter there. This latter approach is preferred. Such events are not expected to occur more than once or twice in the eleven year solar cycle.

The EVA safety haven could be used to provide a pressurizable volume at a remote worksite in case of some emergency requiring rapid pressurization. Such an emergency might be a large leak in the EMU pressure garment or extreme injury or illness of the crewmember requiring immediate attention. The safety haven would need to be transportable in this case, both to be emplaceable next to the current worksite and to allow its transportation to the Station airlock once used. The safety haven would need to interface with the Station airlock to allow transfer of the affected crewmember in a pressurized environment to the Station interior. While this capability is desirable, it is not justified as a requirement and the decision to implement it will have to be made by weighing probability of need versus the cost of implementation.

4.6 SPACE STATION EXTERIOR

The Space Station exterior architecture must provide for:

1. Access to Worksites
2. Compatible and Efficient Workstations
3. Stowage of EVA Tools and Equipment
4. Remote Dependent Life Support Capability
5. Crewmember Safety

Access to worksites is provided by translation aids and restraints. Two types of translation aids, handrails and supplemental aids, are required. Handrails should be provided at all points on the Station exterior to allow manual translation by EVA crewmembers. Exceptions are locations where Station primary structure provides sufficient handholds for such translation. A supplemental aid or aids should be provided to allow rapid crewmember translation over long distances on the Station. Such aids would perform the functions of an elevator or dumbwaiter and would allow the crewmember to move quickly about the Station exterior either unencumbered or while carrying cargo equivalent to a medium module (up to 250 kg. and/or 1 cubic meter). A second type of supplemental aid would also be required, this one to move large modules from point to point on the Station in approximately 20 minutes or less.

Exterior restraints would be required comprising tether points and workstations. Tether points could either be fixed, probably an integral part of each handhold, or mobile, either as the working end of a safety line or sidewire or as part of a supplemental translation aid.

Workstations can either be fixed or mobile, that is, transferrable from worksite to worksite. They should not only firmly restrain the crewmember during work, but should also firmly hold the piece being worked on and any tools and parts required as well.

Sufficient lighting should be provided the crewmember on the Station exterior and at worksites (workstations) to allow unimpaired task performance during both day and night cycles. A tentative minimum of 50 foot-candle area lighting should be provided with the capability to perform 200 foot-candles of spot lighting.

External Stowage is required to permit convenient access to tools, equipment and ORUs, etc., while EVA.

A Dependent Life Support System (umbilical) may be required to provide support for a limited capability EMU Life Support Subsystem, to allow extension of a critical EVA, or to provide closed-cycle operation in the vicinity of sensitive instrumentation.

Safety of EVA crewmembers must be provided for on the Station exterior first by providing standards for exterior equipment design and second by the provision of required safety equipment. In the first case, a design criteria document similar to JSC 10615A "EVA Description and Design Criteria" should be provided for the Space Station to guide Station and payload designers with proper design standards. In the second case, an autonomous capability to retrieve stranded free-floating crewmembers (and debris) must be provided.

NUMBER AND TYPE OF AUXILIARY TRANSLATION AIDS

**OPERATIONAL SPECIFICATIONS: CARGO MASS, TRANSLATION TIMES,
ACCESS DESIGN CONCEPTS/SPECIFICATIONS**

NUMBER AND TYPE OF WORKSTATIONS

**FIXED AND PORTABLE
LOCATIONS**

SITTING OF STOWAGE FACILITIES

OPTIMAL LOCATION

NEED FOR UMBILICAL

SOFT REQUIREMENTS VS COST

SAFETY DESIGN STANDARDS

WHAT ARE THE REQUIREMENTS?

DESIGN CONCEPTS FOR STRANDED CREWMEMBER RESCUE

FREE-FLYER VS SELF-CONTAINED

FIGURE 4-3

SPACE STATION EXTERIOR ISSUES FOR EVA ACCOMMODATIONS

As shown in Figure 4-3, most issues associated with Space Station exterior interface requirements are design issues. Two exceptions exist. The need for a Dependent Life Support System is soft and may not justify the cost. And stranded crew member rescue might possibly be accomplished by some method other than by a free-flying maneuvering unit, at a much smaller cost, but the free-flying unit is the only method in which confidence currently exists.

4.7 SPACE STATION INTERIOR

Space Station interior EVA interfaces must provide:

1. Stowage for EMUs, Support Equipment and Spares
2. An EVA Preparation Area
3. An EVA Servicing, Maintenance and Checkout Area
4. An EVA Planning/Training Area

Examination of various impacts and considerations allows allocation of the four functions above to Station modules. The impacts and considerations are:

1. Volume Required
2. Utilities and Systems Interfaces Required
3. Proximity of Related Functions

The functions, then, are allocated as shown in Table 4-3.

	STOWAGE	PREP/POST	SERVICING	MAINT.	CHECKOUT	PLANNING
AIRLOCK/EVA MODULE	PREFERRED	MANDATORY	MANDATORY	PREFERRED	MANDATORY	OPTION
HAB MODULE	OPTION			OPTION		PREFERRED
LOG MODULE	OPTION (SPARES)					

TABLE 4-3
ALLOCATION OF INTERIOR REQUIREMENTS TO AREAS

The Airlock/EVA module is the only logical location which satisfies EVA requirements in that it minimizes volume impacts to other SS modules and integrates operational requirements with utilities and system interface locations. However, some assembly, sub-assembly or component maintenance tasks may require a specialized maintenance environment depending on actual ORU definition, trouble shooting and post maintenance test requirements and cleanliness requirements. This might take the form of a "cleanroom" - like area in a Hab module.

4.8 SPACE STATION AIRLOCK

The primary function of the Station airlock is to provide a safe, efficient means of transferring men and equipment to and from the vacuum of space without imposing any adverse effects on Station operations. As noted above, it must also have provisions for storage of EVA equipment and must provide EVA system servicing and maintenance equipment including automatic servicing and

checkout equipment. It is highly desirable to minimize the amount of gas lost with each cycle to vacuum. Therefore airlock depressurized volume should be kept to a minimum and as much atmosphere as possible and cost-effective should be retained and recycled.

A programmatic requirement for a hyperbaric chamber has also been levied with the airlock being the preferred location for this chamber. It must accommodate two crewmen and such medical equipment as required during hyperbaric treatment, as well as specified biomedical monitoring apparatus. It must be capable of operation at six atmospheres for two hours, thereafter following a standard Navy decompression profile back to cabin atmosphere.

SECTION 5

SUMMARY

5.1 STUDY OBJECTIVES ACHIEVED

As they were defined by the Statement of Work, our study objectives were achieved by survey and research, analyses and trade studies. We have developed what we consider to be a comprehensive set of design requirements for the Space Station EVAS and its interfacing and supporting systems.

In addition to the study contract objectives, the McDonnell-Douglas team had several other objectives in mind. First, we were determined to assist NASA in justifying a productive EVA capability for the Space Station program. As adamant EVA advocates we were strongly motivated to see that EVA and its attendant systems and accommodations received the programmatic attention they deserved. Secondly, we were fresh from our experiences in developing and conducting the STS EVA missions and eager to apply the lessons learned to the Space Station development effort. We were confident that as a continuing part of the NASA-led SS development team, we would share in the downstream benefits of a strong front end effort. Finally, and taking our cue from a theme consistent throughout the SOW, we wanted to make sure that all EVA system definition and development efforts were sensitive to human productivity aspects and impacts which are so often expressed in non-quantifiable terms.

Our first objective was shown to have been naively conceived as our mission requirements survey resulted in an EVA mission model which demands EVA services on a sustained and routine basis. Even with peak needs exceeding 3000 manhours in a year, the model must be considered conservative, since the SS maintenance, servicing, and repair requirements are poorly defined at this time and there is virtually no data to support the unplanned or contingency requirements which have been responsible for so much of the STS recent EVA requirements. We must continue to recognize that our mission model, as well as those we are aware of being utilized in SS Phase B trade studies, are indeed conservative and may not represent the full scope of EVA requirements for the Space Station.

Throughout the study we were careful to apply the lessons learned from the STS EVA experience base to our analyses and trade studies and found this background useful in identifying truly useful

advancements, in weighting trade-off criteria or in assessing all the ramifications of a new requirement or concept. Extrapolating from this base also enabled us to characterize the key differences in EVA capabilities and limitations between the STS and the SS. While we feel we were thus successful in meeting our second objective we recognize that there is a continuing need for NASA and the Space Station contractors to pursue this goal in the development of EVA systems.

With regards to the emphasis placed on human productivity aspects of EVA designs, we made a concerted effort to bias our trades in favor of productivity, even to the point of ignoring development cost as a discriminator between design options. So far, our conviction that maximizing the use of the crew as the most critical SS resource was the highest priority is being borne out by the EVAS cost trades being performed in the Phase B arena. We will have a continuing concern, though, that there will be productivity impacts resulting from priorities established for distributing limited SS development funds and minimizing those impacts will be a major challenge to the program. The savings in operational costs will be the future dividend of that effort.

5.2 AREAS REQUIRING FURTHER STUDY

Phase B studies will continue to refine EVAS requirements during the SS preliminary design phase, and both contractor and NASA Advanced Development programs will continue to develop the necessary technologies. We strongly recommend that emphasis be placed in the following areas as the program advances (Figure 5-1).

5.2.1 KEY ISSUES

The SS program has already recognized the importance of the radiation exposure issue as it affects the SS as a whole. We feel that this is the proper perspective to take considering the frequency, duration, and dose rate of the possible crew exposures, both IV and EV.

So long as space suit mobility remains affected by suit pressure, we must look for ways to improve the technology or lower the suit pressure. This is especially true for the gloves where even a technology breakthrough would be enhanced even further by lowering the operating pressure. However difficult it is to measure the impacts of this problem on overall EVA productivity, we are convinced that it will significantly affect the productive utilization of EVA as a valuable program resource.

While we are convinced that a maneuvering propulsion capability should be a part of the advanced EVAS, we recognize that the justification for it is not as firmly rooted in mission requirements as are the justifications for other systems. The cost of providing this capability should be carefully balanced against